Shale Gas Potential of the Lower Goru Formation over the Lakhra High in Lower Indus Basin, Pakistan*

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Search and Discovery Article #80373 (2014)**
Posted May 12, 2014

*Adapted from oral presentation presented at AAPG Annual Convention and Exhibition, Pittsburgh, Pennsylvania, May 19-22, 2013
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Abstract

Due to the continuous depleting nature of conventional reserves in Pakistan, the unconventional resources particularly shale gas has gained significant importance. Potential of shale gas in Lower Indus Basin remains largely unknown due to limited data in shales because wells are usually drilled at the highs targeting conventional reservoirs. On the other hand, mature source rocks are located in the lows or synclines. However, an attempt has been made to evaluate Shale Gas potential of Lower Goru Shales over Lakhra High in the Lower Indus Basin by using geochemical and geological data from seven wells.

Lakhra High is a north-south oriented, gentle fold between the Laki Range and the Indus River, and it appears to be the eastern most structure resulting from collisions of the Arabian, Eurasian, and Indian tectonic plates. To date only eight wells are drilled near the high targeting Early Cretaceous age Lower Goru Formation at structural traps. The conventional potential of these wells is unproductive due to poor quality reservoir. However, unconventional potential of Lower Goru Formation over the High still needs to be developed. The Lower Goru Formation was deposited in the deltaic settings over the westward dipping passive margin. The Formation is divided into seven members namely; Upper Sands (Youngest), Upper Shale, Middle Sands, Lower Shale, Upper Basal Sands, Talhar Shale and Lower Basal Sands (Oldest).

Results of the current study show that all shale units comprise of Type II and Type III Kerogen with a TOC in a range of 0.5-5.0%. All the shale units are more than 50m thick and are present at a depth of 2,700-3,500m. The Upper and Lower Shale units are considered as immature whereas Talhar Shale is in the wet gas to dry gas window based on the maturity data of surrounding wells. Talhar Shale possesses the required brittleness for hydraulic fracturing.

The study lead us to conduct 3-D basin modeling study, specialized core analysis and re-evaluation of available geochemical data in future to refine our results and establish prospects for shale gas.
SHALE GAS POTENTIAL OF THE LOWER GORU FORMATION OVER THE LAKHRA HIGH IN LOWER INDUS BASIN, PAKISTAN

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OUTLINE OF THE PRESENTATION

- General Description of the Area
- Available Data
- Geological & Geochemical Characteristics of Shale Units
- Comparison of Shale Potential
- Conclusion & Way Forward
Area of 740 Sq Km available
- Sindh Province
- 50-130 m amsl
- Less populated
- Water resource
- Easily accessible
GEOLOGICAL MAP & REGIONAL CROSS SECTION

- North trending anticline
- Paleocene exposed in the core
- Located in the foothills of Kirthar Fold belt
- 30 Km wide & 100 Km long
- Cretaceous at shallow depth due to Paleocene Exposure but impacts the maturity
- Less deformed comparing to the West

Ref: USGS Bulletin 2208-C
Ref: GSP, 1993
Scale: 1:1000,000
STRATIGRAPHY & PETROLEUM SYSTEM ELEMENTS

- Lower Goru Fm 1700m thick
  - Inner – Middle Shelf fines (upper part)
  - Outer Shelf fines (lower part)
- Based on Sand-Shale sequences, clearly divided into Seven (07) Members in the East;
  - Upper Sand (Con. Reservoir)
  - **Upper Shale***
  - Middle Sand (Con. Reservoir)
  - **Lower Shale***
  - Basal Sand (Con. Reservoir)
  - **Talhar Shale*** (Potential source)
  - Massive Sand (Proven reservoir)
- Proven reservoir units pinching out in the area, comprises siltstones & thinly bedded sandstones

* Potential Shale Gas Candidates
EXPLORATION HISTORY OF LAKHRA HIGH

- Since 1957; 08 wells have been drilled (All Dry Holes)
- Targets were Conventional Reservoirs;(i) Early Cretaceous, (ii) Late Cretaceous & (iii) Paleocene
- Several Oil and Gas Discoveries in the East
- Proven Source Rock: Sembar Shales (Late J - Early K)
- Potential source rock: Lower Goru Shales
- Reservoir Quality was key failure issue for Lower Goru
- Lower Goru Shales have high Gas shows in “Well A”

Ref: USGS Bulletin 2208-C
**DATABASE**

<table>
<thead>
<tr>
<th>Well</th>
<th>Wireline Logs</th>
<th>Geochemical data</th>
<th>Source of Geochemical data</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td>G R</td>
<td>T O C S S S T m a x</td>
<td>IEDS Study, 1995</td>
</tr>
<tr>
<td></td>
<td>D T</td>
<td>S 1 S 2 S 3 V R</td>
<td>PPL-ENI Joint Study, 2011</td>
</tr>
<tr>
<td></td>
<td>R E S</td>
<td>V I max</td>
<td></td>
</tr>
<tr>
<td></td>
<td>R H O</td>
<td>Visual Kerogen</td>
<td></td>
</tr>
<tr>
<td></td>
<td>N P H I</td>
<td>Facies Log</td>
<td></td>
</tr>
<tr>
<td></td>
<td>P E F</td>
<td>XRD Data</td>
<td></td>
</tr>
</tbody>
</table>

- **Well B**: Available (Pakistan Regional Geochemical Study, 1989)
- **Well C**: Available
- **Well D**: Available
- **Well E**: Available (OGDC Basin Study, 2007)
- **Well F**: Available (Weatherford Geochemical analysis, 2012)

- 06 wells data available; 04 wells inside & 02 wells outside the study area
- Regional Studies in Lower & Middle Indus Basins by IEDS in 1995 & OGDCL in 2007
- Geochemical data based on well cuttings except “F well” (9m core in Talhar Shale)
- Facies Log available in only “Well A” (IEDS Study, 1995)
PALEOGEOGRAPHIC MAP OF LOWER GORU FM

( Modified after IEDS Study, 1995 )

Regional Paleogeographic Map of Lower Goru Fm during Early Aptian Time (IEDS Study, 1995)

- Shelfal fines grading landwards into inner shelf sands and delta front interbeds
- Fluvio Deltaic facies

- Facies Log modified / extrapolated to other wells after calibrating with GR & DT Log in “Well A”
- Prepared Regional Correlation Panels along and perpendicular to the Depositional Dip
Geological, Geochemical & Petrophysical Properties of Talhar Shale
GEOLOGICAL CHARACTERISTICS OF TALHAR SHALE

- Depth: **3000-3400m**
- Shallower in the North
- Thickness: **80-140m**
- Thicker in the South
- Lithology:
  - **Shale:** Dark gray, fissile, pyritic, silty, occ highly carbonaceous, slightly to non calcareous
  - **Siltstone:** Light to medium gray, soft to moderately hard, blocky, sl. pyritic, non calcareous
  - **Sandstone:** Quartzitic, fine to med grained, friable
- **Mineralogy**: Clay (<30%), Silica (67%) & Carbonates (5%)

* XRD data of an offset well
GEOCHEMICAL CHARACTERISTICS OF TALHAR SHALE

- Depositional Environment: Prodeltaic to outer Shelf
- TOC: 1.5-4.7%
- Visual Kerogen assessment suggests;
  - Dominant Type II & Subordinate Type III Kerogen
  - Maturity**: No reliable VR & Tmax data over High 3- TAI (equivalent to 1.2 % VR)
  **Poor quality samples with mud additives
LATERAL DISTRIBUTION OF TALHAR SHALE

- Well “E” 44.5 Km
- Well “A” 59 Km
- Well “C” 9 Km
- Well “D”

Petrophysical Properties

<table>
<thead>
<tr>
<th>Well</th>
<th>A (South)</th>
<th>Well in South</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR (gAPI)</td>
<td>75-100</td>
<td>80-110</td>
</tr>
<tr>
<td>DT (us/ft)</td>
<td>80-100</td>
<td>70-90</td>
</tr>
<tr>
<td>LLD (ohm.m)</td>
<td>2.4-3.8</td>
<td>5-10</td>
</tr>
<tr>
<td>RHOB (g/cm3)</td>
<td>2.46-2.66</td>
<td>2.60-2.72</td>
</tr>
<tr>
<td>NPHI (m3/m3)</td>
<td>0.14-0.23</td>
<td>0.16-0.28</td>
</tr>
</tbody>
</table>

- Widely developed in the area
- Outer Shelf- Prodeltaic facies
- 2-3 % TOC in the area
Geological, Geochemical & Petrophysical Properties of Lower Shale
GEOLOGICAL CHARACTERISTICS OF LOWER SHALE

- Depth: **2200-3000m**
- Shallower in the North
- Thickness: **375-640m**
- Thicker in the North
- Lithology:
  - *Shales*: Light to medium gray, fissile, pyritic, silty, slightly to non calcareous, rarely glauconitic in lower part
  - *Siltstone*: Light brnsh gray, moderately hard, micaeous, slightly to non calcareous, at places grading to v fn Sst
  - *Sandstone*: Quartzitic, fine to medium grained, moderately hard, pyritic, calcareous
- Mineralogy*: Clay (45%), Silica (40-45%), Carbonates (8-10%)

* Based on XRD data of “Well A”
GEOCHEMICAL CHARACTERISTICS OF LOWER SHALE

- Depositional Environment: Prodeltaic to outer Shelf
- TOC: 0.6 – 4%
- Upper part has Type III & IV Kerogen
- Lower part has Type II-III Kerogen
- Maturity**: Oil – Wet Gas Window

(Based on TAI 2+ to3- values)

** VR data is not reliable due to difficulty in differentiation b/w woody & inertinitic OM
- Clay (45%), Silica (40-45%), Carbonates (8-10%)
- Considering GR response, lower part of Lower Shale may have low clay content as compared to highlighted part.
LATERAL DISTRIBUTION OF LOWER SHALE

- Widely developed in the area
- Outer Shelf to Prodeltaic facies
- Lower part more organic rich (2-3 % TOC)
- 100-300 m thick Lower part

Petrophysical Properties

<table>
<thead>
<tr>
<th>Well</th>
<th>A</th>
<th>Well in South</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR (gAPI)</td>
<td>75-125</td>
<td>80-120</td>
</tr>
<tr>
<td>DT (us/ft)</td>
<td>80-100</td>
<td>70-90</td>
</tr>
<tr>
<td>LLD (ohm.m)</td>
<td>2.4-3.8</td>
<td>5-7.5</td>
</tr>
<tr>
<td>RHOB (g/cm3)</td>
<td>2.3-2.5</td>
<td>2.4-2.6</td>
</tr>
<tr>
<td>NPHI (m3/m3)</td>
<td>0.2-0.4</td>
<td>0.2-0.33</td>
</tr>
</tbody>
</table>
Geological, Geochemical & Petrophysical Properties of Upper Shale
GEOLOGICAL CHARACTERISTICS OF UPPER SHALE

- Depth: **1800-2200m**
- Shallower in the North
- Thickness: **200-400m**
- Thicker in the North East
- Lithology:
  - **Shales:** Medium to dark gray, sub fissile - fissile, occ sl. Silty, slightly to non calcareous, iron stained
  - **Siltstone:** Lt. olive gray to olive grey, moderately hard, blocky, calcareous, at places grading to v fn-mgd grnd Sst
- Mineralogy: Not Available
GEOCHEMICAL CHARACTERISTICS OF UPPER SHALE

- Dep. Environment: Offshore-Upper Shoreface
- TOC: 0.5 – 2.0%
- Type II-III, Type III & Type IV Kerogen
- Dominantly Woody & Inertinitic,
- Sub-ordinate Amorphous & Herbaceous
- Maturity: No reliable data available
LATERAL DISTRIBUTION OF UPPER SHALE

- Widely developed in the area
- Middle shoreface to Offshore facies
- 1-1.5% TOC in the area
- Variable thickness (200-400m)

Petrophysical Properties

<table>
<thead>
<tr>
<th>Wells</th>
<th>A</th>
<th>Well in South</th>
</tr>
</thead>
<tbody>
<tr>
<td>GR (gAPI)</td>
<td>75-100</td>
<td>90-110</td>
</tr>
<tr>
<td>DT (us/ft)</td>
<td>80-100</td>
<td>90-110</td>
</tr>
<tr>
<td>LLD (ohm.m)</td>
<td>1.7-3.8</td>
<td>1-5</td>
</tr>
<tr>
<td>RHOB (g/cm³)</td>
<td>2.4-2.6</td>
<td>2.4-2.6</td>
</tr>
<tr>
<td>NPHI (m³/m³)</td>
<td>0.1-0.3</td>
<td>0.2-0.33</td>
</tr>
</tbody>
</table>
 Lower Goru is in Oil to Wet Gas window Over Lakhra High

Talhar Shale being the deepest shale would have the highest maturity

Reference: OGDC Basin Study, 2007
N-S Structural Cross Section of the Lakhra High

- Based on microscopic parameters (TAI) Top of Wet Gas window is at 3100 m (?)
- Lower part of Lower Shales & Talhar Shale is expected to be in Wet Gas window (?)

2 to 2+ TAI Maturity Eq (0.7 %VR) (Early Oil Window)
6-6.5 SCI Maturity Eq (0.7 %VR) (Early Oil Window)
3- TAI Maturity Eq (1.2 %VR) (Wet Gas window)

Top of Wet Gas window @ 3100m (?)
## COMPARISON OF LOWER GORU SHALE UNITS

<table>
<thead>
<tr>
<th>Shale Unit</th>
<th>Upper Shale</th>
<th>Lower Shales</th>
<th>Talhar Shale</th>
</tr>
</thead>
<tbody>
<tr>
<td></td>
<td></td>
<td>Upper Part</td>
<td>Lower Part</td>
</tr>
<tr>
<td>Thickness (m)</td>
<td>200-400</td>
<td>275-350</td>
<td>100-300</td>
</tr>
<tr>
<td>Depth (m)</td>
<td>1800-2200</td>
<td>2200-2700</td>
<td>2500-3000</td>
</tr>
<tr>
<td>TOC (%)</td>
<td>0.5-2.5</td>
<td>0.6-4.0</td>
<td>2-3</td>
</tr>
<tr>
<td>Kerogen type</td>
<td>II-III, III, IV</td>
<td>III, IV</td>
<td>II-III</td>
</tr>
<tr>
<td>Mineralogy</td>
<td>N/A</td>
<td>Clay (45%), Silica + Carbonate (48-65%)</td>
<td>Clay (&lt;30%), Silica + Carbonate (72%)</td>
</tr>
<tr>
<td>Maturity</td>
<td>Early Oil</td>
<td>Oil-Wet gas</td>
<td>Oil-Wet Gas</td>
</tr>
<tr>
<td>Depositional Environment</td>
<td>Shoreface to Offshore</td>
<td>Prodeltaic to outer Shelf</td>
<td>Outer Shelf</td>
</tr>
</tbody>
</table>

- Considering (i) TOC, (ii) Kerogen type, (iii) Mineralogy & (iv) relatively higher depth for maturity in Wet Gas window; Talhar Shale & Lower part of lower shale seems better among other Lower Goru Shales.
CONCLUSION & WAY FORWARD

Conclusions

- All Lower Goru Shales are geologically thick, having depth of 2-3.5 Km and contain appropriate TOC.
- Lower part of Lower Shale & Talhar Shale posses required Shale reservoir properties
- Kerogen is mostly Type II with some Type III having maturity of Oil-Wet Gas (although uncertainty exists due to contaminated samples)

Way Forward

- Cut 30-40m cores in Lower Shale & Talhar Shale in Upcoming wells over the Lakhra High
- Carryout detailed laboratory analysis including (i) Organic Geochemistry, (ii) Adsorption Gas analysis, (ii) Geomechanical Test, (iii) Rock Physics & (iv) canister gas analysis at wellsite
- Acquire specialized logs (ECS, DSI etc) for mineralogical & geo-mechanical modeling
- Carryout 3D Basin Modeling to estimate GIIP & identify sweet spots for exploratory wells
The Authors acknowledge the support from the Management of Pakistan Petroleum Limited (PPL) for granting permission to share and publish the data.

Our Special Thanks to Dr. Nadeem Ahmed, Dr. Abrar Ahmed & Mr. Mohsin Ali for reviewing the work and providing valuable inputs.
THANK YOU
(Q/A)